THE PERFORMANCE OF
CLOSED LOOP STEEL FIBER CONCRETE

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ABSTRACT

This paper discusses the performance of the steel fiber concrete. When the straight fibers are introduced to the concrete mix, the direction of the steel fibers can be affected by the mould, balling together and random orientation. As the result smaller percentage of the steel fibers are being applicable when compared to the original designed. The closed loop steel fibers technology is to overcome the problem face by straight steel fibers, this is because closed loop fibers design to place the fibers in position where it able to interlock with the aggregate during the concrete mix. There are several test being analysis during this research which is compressive test, flexural test, water absorption test, porosity and segregation test. The different type of test method had been carry out is to determine the performance of the closed loop steel fiber and existing hooked end steel fibers. By adding the closed loop steel fiber, the compressive strength is 32 % from the plain concrete. In addition, the flexural strength is 30 % higher compare to the plain concrete. By using the closed loop steel fiber manage to overcome the segregation by the steel able to interlock with the aggregate instead of passing through it. Concrete cubes and beams were manufactured with a fixed addition of fibers by weight. The outcomes showed an improvement in the performance of the closed loop steel fiber when compared to the hooked end steel fibers. This finding is essential because closed loop steel fibers are not commercially available at the present period.

ABSTRAK

Tesis ini membincangkan prestasi konkrit gentian keluli. Apabila gentian lurus diperkenalkan untuk campuran konkrit, arah gentian keluli boleh dipengaruhi oleh acuan, balling bersama-sama dan orientasi rawak. Sebagai peratusan hasil yang lebih kecil daripada keluli gentian sedang terpakai berbanding dengan yang asal direka. Gelung tertutup gentian keluli teknologi adalah untuk mengatasi masalah wajah dengan gentian keluli lurus, ini adalah kerana reka bentuk gentian gelung tertutup untuk meletakkan gentian dalam kedudukan di mana ia dapat saling dengan agregat dalam campuran konkrit. Terdapat beberapa analisis ujian makhluk dalam kajian ini iaitu ujian mampatan, ujian lenturan, ujian penyerapan air, keliangan dan ujian pengasingan. Jenis yang berbeza daripada kaedah ujian telah menjalankan adalah untuk menentukan prestasi tertutup gentian keluli gelung dan sedia ada ketagih gentian keluli akhir. Dengan menambah tertutup gentian keluli gelung, kekuatan mampatan ialah 32% daripada konkrit biasa. Di samping itu, kekuatan lenturan adalah 30% lebih tinggi berbanding konkrit biasa. Dengan menggunakan gelung serat keluli tertutup berjaya mengatasi pengasingan dengan keluli dapat saling dengan agregat bukan melaluinya. Kiub dan rasuk konkrit telah dihasilkan dengan tambahan tetap gentian mengikut berat. Hasil menunjukkan peningkatan dalam prestasi gentian keluli gelung tertutup apabila dibandingkan dengan ketagih gentian keluli akhir. Penemuan ini adalah penting kerana gentian keluli gelung tertutup tidak boleh didapati secara komersial pada tempoh ini.

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LIST OF SYMBOLS

A	average cross sectional area of the specimen
f_c	Compressive strength
G	Grade
H_S	Submerged mass of specimen
P	Porosity of the specimens
P	Maximum load carried by the specimen during test
ρ_W	Density of water
ρ_{sol}	Density of solids
V_T	Total volume of the specimens
V_{sol}	Volume of the solids
V_{voids}	Volume of the voids
W_D	Dry mass of specimen
$\pm$	Plus minus
%	Percentage

LIST OF ABBREVATIONS

ACI	American Concrete Insitution
ASTM	American society for testing and materials
BS	British Standard
cm^3	Cubic centimeter
d	Depth
g	Gram
kg	Kilogram
kN	Kilonewton
m	Meter
mm^2	milimeter square
MPa	Megapascal
N	Newton
YTL	YTL Corporation Berhad
$\sum$	Summation of

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Steel fiber concrete is one of the special concrete that normal concrete mix with discontinuous discrete steel fiber. There are abundant of small-scale fibers are distribute randomly during the concrete mix (Bandera et al, 2012). The evolution of using steel fibers in the field is to replace and reduce the traditional reinforcement bar in the concrete members (Soetens et al, 2014). Thus steel fiber tend to increase the tensile strength of the concrete by deflecting micro cracks which develop in the concrete under exterior force and load effects (Lee et al, 2010). The lengths of the steel fibers are usually small and short, this is because it wants to avoid inadequate workability of the concrete mixture (Sebaibi et al, 2014).

The objective carry this research is to identify the 2D closed loop of steel fiber that affects the performance of the steel fiber concrete which compare with the normal straight steel fibers (Alan et al, 2013). The challenge of using the straight steel fiber is the fiber may assemble at one location where they cannot function properly which is used as load transfer (Richardson et al, 2013). Since steel fibers consists of weight, during the mix the fibers will tend to stick to the sides in the rotary mixer, as the final result the performance of the steel fiber concrete cannot be greatly increase yet waste of the dosage of the addition. On the other hand the closed loop steel fibers are cast in random layer; this is to make sure the orientation of the steel fiber will not change significantly due to the compaction. The target of using 2D closed loop steel fiber is to increase the performance of the concrete which the fibers able to interlock with the aggregate in the mix (Daniel et al, 2014). The shapes that used during the research are square closed loop steel fiber.

The addition of the steel fiber to the concrete is normally can increase the compressive strength and tensile strength into 8% to 15% (Gebman, Nd). In additional steel for structural purpose steel fibers should be add as supplements to the reinforcement bars. This is because fibers able to limit the percentage of cracking that due to load, thus it also can improve the resistance to material deterioration due to fatigue, shrinkage and thermal stresses (Bandera et al, 2012).

1.2 BACKGROUND

Concrete is one of the most essential materials that used in construction area. Moreover, it able to cast into desired structural shape from cylindrical to rectangular. However, concrete is good and string in compression, but weak in tension. To overcome this issue, reinforcement bars are added to the concrete (Faxing et al, 2006). Generally by adding reinforcement bar to concrete can typically increase it tensile strength up to 10%. The main bar which is longitudinal bar in the structural elements is to resists tensile stresses that apply to it, while for the bars that wrapped around the longitudinal bar is to resist the shear stresses. Generally the role of using reinforcement bar in the structural elements is good, but it mostly increases the tensile strength (Kang et al, 2011). Nevertheless, the issue of cracks in the reinforced concrete still often occurs nowadays, so that the involvement of fiber in the concrete to overcome this problem. Fiber reinforced concrete is the concrete that mix which consists of short and discrete fibers in it (Aliabdo et al, 2013). The amount of the fibers that usually added to the concrete mix is calculated in percentages form from the total volume of the concrete we need (Ali et al, 2013).

Besides that, there include many type of fibers such as steel fibers, polypropylene fibers, glass fibers, and slurry infiltrated fiber (Wafa, Nd). However for the steel fibers, they are normally classified based on their manufacturing process. There contain different shape of steel fibers such as straight, hooked, paddled, deformed, crimped and irregular (Kaikea et al, 2014). The addition of these steel fibers will not significantly improve the compressive strength; merely it will increase the tensile strength and ductility. The most important of adding these steel fibers, they can increase the ability of withstanding after cracking and shear resistance (Neves et al, 2005).

1.3 PROBLEM STATEMENT

The increasing of urbanization and improvement of the developed and developing countries increased the demand of the cement. This is because concrete is the most generally used material in the world. Generally, concrete can be described as the composite material that composed form a coarse granular substances that embedded in a matrix of cement that occupy the space between the particles which glue them together. Although concrete is a widely used materials, it was consider a brittle materials with low tensile strength in nature (Shah et al, 2011). As the revolution and improvement of concrete characteristics was adding reinforcement bar which allow it improves the tensile strength and strain capacity. Reinforcement bar had finally become the alternative materials that to encounter the bending problem in the concrete. However, reinforcement bar may increase the load and dimension of the concrete, fibers were introduced to overcome the problem (Uygunoglu, 2011). There many types of fibers such as steel, glass, organic and etc. (Soylev, 2014).

Besides that, there is present of many types of effect on the concrete for example segregation, honey comb and microcracks (Soetens et al, 2014). The present of the effect will lead to structural defect. So the improvement of the concrete is to solve the present issues in the hardened concrete.

According to researchers, hooked end steel fiber is the better fiber among the steel fiber that available (Soetens et al, 2014). However, during the mix proportion the orientation of the steel fibers are added randomly to the mix. The location of the steel fibers will not locate the design location due to its strip shape that able to allow it to pass through easily between the spaces of the coarse aggregate. In this study, 2D closed steel fibers are used to overcome the issue. During this research, compressive test for cube as well as flexural test for beam are tested and compare between normal concrete and steel fiber concrete.

1.4 OBJECTIVE

2D closed fiber is the new technology that cast in random layer of the concrete. Through this, closed loop fiber able to improve the performance as strip shape fiber to concrete such as tensile strength, flexural strength as well as post-cracking performance.

The aims of carry out this research are

1. To analysis the performance of the closed loop steel fiber in the concrete.
2. To overcome the problems that caused by the current steel fiber that available in the market.
3. To study the mechanical properties of the closed loop steel fiber and hooked end steel fiber in the concrete.

1.5 SCOPE OF WORK

In order to achieve the aim of the study, destructive and non-destructive test are used. The compressive test is test for cube, flexural test is analysis the performance of the beam and pull out test is to determine the bond behavior of the prestressing strands for the materials. However, the non-destructive test will be rebound hammer and ultrasonic pulse velocity test as well as slump test.

The concrete grade 30 was used during the experiment. The type of the steel fiber used are closed loop square fiber (25.4 mm x 25.4 mm) and hooked end steel fiber with length 60 mm and diameter with 0.75 mm during this experiment. The amount of steel fibers is limit to 1% from the volume of the concrete.

1.6 RESEARCH SIGNIFICANT

Since steel fiber is one of the famous and common fiber that used in the construction area (Vairagade et al, Nd), as the 2D closed loop steel fiber design is to maximize the function of the fiber that used for steel fiber concrete. As the steel fiber able to increase the post cracking and tension stress, so it is possible to reduce and resize the shape or amount of the reinforcement bar in the structural elements since it is consider one of the expensive materials. In addition, by adding the steel fiber is to improve the strength of shear and ductility, thus the most essential idea is to control the crack and make sure it will not occurred large width crack in the future.

Besides that the BRC is considerable cheap and is easily available in the market. Thus the cost by adding steel fiber to concrete will not change significantly. According to some researchers, they found out that hooked end steel fiber is the better type of shape (Soetens et al, 2014). Besides that, the shape of the steel fiber is change form strip to 2D closed loop; this is to make sure the 2D closed loop steel fiber able to overcome the problems that cause by strip shape fibers (Kim et al, 2014). As mentioned earlier, 2D closed loop fiber able to interlock with the aggregate during the mixing process and the location of the fiber will not clump together unlike strip shape fibers.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter concrete such as high performance concrete, self-healing concrete, and fiber concrete are discussed. In the present day, we have different type of fibers, such as glass fiber, steel fiber, and slurry infiltrated fiber. Besides that, the advantages and limitation of using steel fiber will be discussed. Every material has their own advantages and disadvantages same goes to steel fiber. When there is extra material that added to the normal plain concrete, there will be changes of their own performance, for example mechanical properties, durability, toughness and compressive strength. Different type of concrete have their personal application, the changes of normal plain concrete to special concrete this is to make sure the concrete able to withstand the surrounding around it.

2.2 CONCRETE

Concrete is one of the most common and widely used as man-made construction material (Gambir, 2006), thus it is very obviously seen like concrete is the most essential key element in this field (Woodson, Nd). Concrete is the mixture of coarse aggregates, fine aggregate (sand), cement and water (Najim et al, 2010). The most common cement that usually used to produce concrete is Portland cement (Ingram, Nd). This is because Portland cement is known as hydraulic cements, they able to set and harden through reacting chemically with water under hydration process (Woodson, Nd). While the hardening process of the concrete is continuous for a long period of time, this is because the concrete grows stronger with age (Chen et al, 2013).

The strength, durability and some common characteristics of concrete are mostly depend upon the properties of the materials, the mix proportions, method of compaction and also controls during placing, curing and compacting (Gambhir, 2006). Moreover the key of producing strong, durable and uniform concrete is to carefully control the basic procedure and progress. Firstly is the type of the cement used during the mix, the most common used is Portland cement since it consists of calcium, silicon, oxygen, aluminum and iron. Next will be the aggregates, they are consider as the primarily naturally-occurring materials, the aggregates that used should be in the inert form, this is to prevent further reaction with other chemical with the aggregates (Gambhir, 2006). One of the most essential materials is water, this is because water is the cement will react chemically with the present of water to form cement paste, without sufficient water there will be not enough of calcium-silicate-hydrate gel being produced, this will affect the quality of the concrete (Lydon, Nd).

Generally, concrete is known as it is good in compressive strength while the tensile strength is very low (Zhang, 2015). To overcome this issue there add reinforcing bar to it. The compressive strength of the normal concrete is the range of 25MPa to 55MPa (Shang et al, 2014). A good concrete is produced to satisfy the performance requirement in the plastic state and harden state, so that we can avoid uncertain circumstances like cracking in the future. During the plastic state, the concrete should be workable and free form segregation and bleeding. While for the harden state, the concrete should be strong, durable and impermeable, yet it also must have minimum dimensional changes (Mehta, Nd).

2.2.1 High Performance Concrete

High performance concrete initially named as concrete of high resistance (Benamara et al, 2014). The design of this kind of concrete is to provide several advantages in the construction of concrete structures which the criteria is difficult achieve by normal concrete that involve of conventional ingredients, normal mixing and curing practices (Gambhir, 2006). The range of the compressive strength of high performance concrete is within 60 MPa till 100 MPa (Bharatkumar, Nd). The main difference of high performance concrete and conventional type concrete is addition of chemical admixtures and mineral admixtures (Aitcin, 2003). The function of using the chemical admixtures is to reduce the quantity of water usage in the mix, so that it can reduce the porosity within the hydrated cement paste, as a result a higher density of concrete able to be produced. The water/cement ratio is always below 0.35 (Khalifa, 2009). Moreover, the mineral admixtures also known as cement replacement, it act as fine filler that will turn the concrete become denser and stronger (Kaikea et al, 2014).

Generally, the high performance concrete is known as high strength and low permeability. Those characteristic are link with each other, this is because high strength required low volume of pores, especially for the larger capillary pores (Kukko, 2007). The solution to obtain a low volume of pores for the mix is to make sure the particles that used had already graded down to the finest size, to achieve this condition mineral admixture which is pozzolanic material had been added to the mix, the example of the admixtures are silica fume, fly ash and etc. This is because most of the pozzolanic materials are finer than cement, so that it is able to fill the spaces either between the cement particles or between cement and aggregates (Al-jabri et al, 2009). The strength of coarse aggregate to making high performance concrete is very crucial. In consequence, the good quality of the aggregate should be used during the mix. To make sure the good bonding between the aggregate and cement, the shape of these particles should be approximately equal dimensional. In addition, the aggregate should be crushed situation, this is because the impact of the crushed aggregate able to develop few elongated and flaky result. Nevertheless, gravel is the most satisfactory shape to be used to produce high performance concrete (Mehta, Nd). Besides that, cleanliness of the coarse aggregate, absence from dust, and lastly is uniformity of the grading are very important factors to be determined (Konig, Nd). Durability of the aggregate is critical when the concrete is exposed to the freezing and thawing. However, the form of the fine aggregate should be in the round and uniformly graded, this is because the mixes of the high performance concrete contain high content of fine particles, and the range of the modulus fineness is in the range of 2.8 till 3.2 (Holschemarcher, 2010).

High performance concrete is one of the famous materials used in the construction area due to its properties, for example high rise building (KLCC). This is no doubt that the use of high performance concrete will continue to grow.

2.2.2 Self-compacting Concrete

Self-compacting concrete is one of the family members of tailored concrete with some special engineered characteristics (Mindness, Nd). The most well-known properties of self-compacting concrete is the concrete able to flow and fill the entire formwork with its own self weight without any external help such as vibrator machine or poker (Almeida et al, 2010). The improvement of this kind of concrete had greatly improved the working condition in the construction period, yet it had been increase the quality of the concrete. In addition, self-compacting concrete had provided more space for architectural design (Almeidafilho, 2010).

To produce self-compacting concrete it need high quality control during the production, transportation and placing compare to normal plain concrete and high performance concrete (Nayak et al, Nd). So that the mixing process should be done in the batching plant, thus the mixing period of these concrete is longer than normal plain concrete (Subramanina et al, 2002). In addition the self-compacting concrete should be transported by using transit mixer to the construct location. The placing or pouring of this concrete including pump, so that the period of placing the concrete can be greatly reduced as compared to normal concrete (Efnarc, 2005). Since there is no vibration needed for the self-compacting concrete, the placing time had been reduced. There is some precaution need to be alert that is the design should including the supporting system (Nayak et al, Nd). Moreover, the curing process is very essential and more critical as compare to normal plain concrete, this is because the amount of the fine aggregates in the self-compacting concrete is higher than normal concrete and same goes to amount of the bleed water is less (Rao, et al, 2002). If the curing period and method is wrong as a result cracks will develop. After the concreting is done, the top surface should not exposed to open air and suggested to cover the surface with burlaps for proper curing process continue for at least 10 days (Vanhove et al, 2000).

Self-compacting concrete is the gift for construction area, where the infrastructure projects that need long service life and limited construction period (Liberato, 2007). As these concrete able to place form 5m free fall and able to spreads up to 12m without any segregation (Azeredo et al, 2013). According to the ability of self-compacting concrete, it can pass through very complicated shape without external help. As a result negligible of defect as the final product (Pop et al, 2013).

2.2.3 Fiber Concrete

Fiber concrete is a type of concrete which contain a certain amount of discrete number of short fiber in the concrete (Shah et al, 1971). The orientation of the fibers is mostly place and dispersed randomly in the mix. There are different type of fibers are available in the market such as steel fibers, synthetic fibers, slurry infiltrated fibers, SIMCON and natural materials (Krenhel, Nd). The involvement of the fiber is there is present of plenty micro crack in the concrete, thus the micro crack is the rapid propagation when there is an applied stress on it, since the concrete known as weak in compressive strength. The addition of the fiber into the concrete can increased the flexural strength because the fibers are closely spaced fibers that will block the occurrence of micro cracks. However the size and volume of the fibers that should be added to the concrete are depend on the type of the fibers use and the function of the particular fibers. Nevertheless, the most common fiber that use in the concrete is steel fibers (Bentur, 2007).

In contrast with the reinforced concrete, since the reinforcement bar is all placed nicely in the concrete while the fiber is all placed mostly randomly around the mix. This is because the function of the reinforcement bar is too optimize and increase the tensile strength of it, thus it is necessary the orientation should place carefully (Kassoul et al, 2010). On the other hand, the fibers that add into the concrete manage to improve their mechanical properties such as tensile, flexural and compressive strength. The most important adding fiber to the concrete is to behave as crack arrestor (Aarup, 2004).

The plain concrete will tend to fail once when there deflection is exceed the ultimate flexural strength, however the fiber concrete will continue to support some the considerable loads even it had already deflect (Banthia et al, 2003). Based on the ACI committee study, the amount of the energy that had been adsorbed by the fiber bonding is calculated through the area which is under the load deflection curve before it had completely separate from the beam which is 10 to 40 times in the fiber concrete higher than normal plan concrete (Chalioris, 2011).

2.2.3.1 Synthetic Fiber

Synthetic fiber is a manmade fiber. There are some common type of these fibers such as carbon, aramid and nylon. Those fibers have their own properties and characteristics, so different function use different type of these particular fibers. Since synthetic had been providing good benefit to concrete, each of the application for every type of these fibers will be discussed at the following paragraphs.

2.2.3.2 Carbon Synthetic Fiber

The development of carbon fiber is to provide a high strength and have a stiffness characteristic which is more focus on the aerospace industry (Lambrenchts, Nd). Carbon fiber is considering the most expensive fiber among the synthetic fiber, so that there is less commercial development that used carbon fiber. One of the potential using this fiber is they are light in weight with outstanding mechanical properties (Kubo et al, 2005). The materials that produce carbon fibers are come from petroleum and coal pitch which is cheaper than poly-acrylonitrile fiber (Nayak et al, Nd).

Generally, carbon fiber is well known as strong and thin. One of the reason that kept this fiber using in the aerospace industry is they have high tensile strength and elastic modulus, so that they able to hold the concrete and increase the performance of the concrete (Nayak et al, Nd). Besides, carbon is also almost inert to most of the chemical, thus they will not occur chemical reaction in the future.

2.2.3.3 Aramid Synthetic Fiber

Aramid synthetic fiber also known as aromatic polyamide fiber that made from polymeric materials. The first discover of this fiber is in year 1965 and it is the first organic fiber with characteristic of high modulus (Jassal et al, 2001). The mechanical properties of the cement matrix with these fibers are attractive with each other. Due to the high cost of this fiber, it also had limitation to use in the commercial buildings or structures.

In addition, aramid has a higher mechanical properties than other synthetic fibers which at least 5% (Jassal et al, 2001). There are two different methods to produce this fiber which are low-temperature polycondensation and direct polycondensation in the solution by using phosphites (Jasal et al, 2001). Based on these two method, the second method is more preferable, this is because there consist of interfacial polymerization inside the molecular weight distribution which is not suitable using the low temperature to produce it. So that solution is the more acceptable to make this fiber, the solvent that used is dimethyl acetamide and tetra methyl urea.

Moreover, the strength of this fiber will not be affected up to 160^0C (Burgoyne, Nd). Aramid fibers have very good properties which able to fulfill lots of applications such as marine and aircraft.

2.2.3.4 Nylon

Nylon is the come from the polymers family because it presence of the amide properties. Currently in the market there consist of two type nylon fibers which are nylon 6 and nylon 66 (Hegde et al, 2004). Basically, the nylon fibers are produced from nylon polymers. This process undergoes several steps such as extrusion, stretching and heating then it will only form oriented fiber form. To improve the properties of the nylon fiber, it can enhance through some special and particular treatment such as heating and air texturing. In addition, the nylon fibers are available in many forms such as multifilament yarns, staple and etc. (Nayak et al, Nd). However, for the concrete purpose, the fibers should be high tenacity heat and also light, thus it also needs to cut into short length.

The properties of nylon fibers are they have good tenacity, excellent toughness and good in elastic recovery. Besides that, nylon also consider as inert material, so it is resistant to large variety of organic and inorganic substances which including reactive alkali (Walker, 2012). Most of the application that uses nylon is the manufacture of the split table-pie fibers. However, due to the higher cost of this fiber, it had been limit to some specialized purpose. Recently the purpose of using this concrete are mostly used in pavement slabs and repairing work.